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# EPA's LIMB (Environmental Protection Agency's Limestone Injection Multistage Burner) Research, Development, and Demonstration Program

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16. ABSTRACT The paper describes and discusses key design features of the retrofit of EPA's Limestone Injection Multistage Burner (LIMB) system to an operating, wall-fired utility boiler at Ohio Edison's Edgewater Station, based on the preliminary engineering design. It further describes results of pertinent projects in EPA's LIMB program and shows how these results were used as the basis for the design of the system. The full-scale demonstration is expected to prove the effectiveness and cost of the LIMB concept for use on large-scale utility boilers. To date, a preliminary engineering design for the Edgewater unit has been prepared incorporating the technology developed in smaller-scale studies. The schedule calls for system start-up by March 1987. EPA is engaged in a multi-year program to develop an improved control technology for emission of sulfur and nitrogen oxides (SOx and NOx) from the combustion of fossil fuels. The technology, called LIMB, involves staged-flow coal burners and injection of a reactive sorbent into the furnace to reduce emissions. The program includes fundamental studies of reaction chemistry and kinetics, bench and pilot scale experimental studies, a full-scale demonstration, and economic and applicability studies. It is structured to establish a basis for future public sector commercialization, as well as help understand the technology's controlling factors.

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# EPA'S LIMB RESEARCH, DEVELOPMENT, AND DEMONSTRATION PROGRAM

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## INTRODUCTION

The U.S. Environmental Protection Agency is engaged in a research program to develop improved control technologies for emissions of sulfur and nitrogen oxides ($SO_x$ and $NO_x$) from the combustion of fossil fuels. These emissions are important because of their magnitude and their apparent link to acid rain. The cause and potential solutions of the acid rain problem are still being debated; however, control of $SO_x$ and $NO_x$ from power plants is a major element in all proposed control strategies.

The choice of control techniques for acid rain will likely include a mix of technologies to achieve the mandated pollutant reduction at a cost that will minimize the impact on the nation and on specific geographical areas. Commercially available options include coal switching, coal cleaning, and various types of flue gas desulfurization (FGD) systems. In addition, analysis indicates that low capital cost technology for retrofit to existing boilers would provide further flexibility in control strategy even at moderate (e.g., 50%) $SO_2$ removal rates. One such technology is LIMB (acronym for Limestone Injection Multistage Burner), which is based on the injection of dry sorbents into the boiler for direct capture of $SO_2$ from the combustion gases. LIMB combines sorbent injection for $SO_x$ control with the use of low-$NO_x$ burners, in which staged combustion is utilized for $NO_x$ control.

## EPA LIMB PROGRAM

The EPA LIMB program was initiated in 1981, although work in related areas had been conducted by EPA and others prior to that time. The LIMB program is structured to provide an understanding of the controlling factors in the LIMB process and to establish a basis for private sector commercialization of the technology. EPA ultimately expects to show that LIMB is a low cost control technology capable of producing moderate $SO_x$ and $NO_x$ control (50-60%) with applicability for retrofit to the major portion of the existing coal-fired boiler population. Work in the LIMB program has been concentrated in four major areas.

- Generic research is conducted to provide an understanding of the important factors in the process. The work has focused primarily on identifying reaction chemistry and kinetics and on improving sorbent reactivity for greater process efficiency.

- Prototype testing is carried out in both small and large pilot plant systems in which basic research data are further confirmed and design criteria are developed.

- A full-scale demonstration of LIMB is under way on a wall-fired utility boiler to demonstrate the cost and effectiveness of the technology under actual retrofit conditions. A demonstration on a tangentially fired boiler is also being considered.

- Finally, studies to generalize the technology by defining criteria for application of LIMB to a wide range of boiler designs, coals, and sorbents are being conducted. These will be accomplished by a combination of modelling techniques and supporting measurements on operating boilers.

The Wall-Fired LIMB Demonstration is the current focal point of the LIMB program, and much of the recent research activity has been oriented toward support of the Demonstration. This paper will emphasize those parts of the research program which directly support the Demonstration and will point out how these research results were translated into the design of a practical retrofit LIMB system on a 105 MW utility boiler. However, it must be recognized that this discussion includes only the most recent findings in selected areas of a broader research program aimed at application of LIMB technology to coal-fired utility boilers.

## WALL-FIRED LIMB DEMONSTRATION

The EPA Wall-Fired LIMB Demonstration is a 4-year project that includes design and installation of a LIMB system at the 105 MW Unit 4 boiler at Ohio Edison's Edgewater Station in Lorain, Ohio. The project plan calls for a full year of operating and testing to demonstrate its capabilities. EPA is sharing the cost of the project with the major project participants - the State of Ohio, Ohio Edison, and Babcock & Wilcox (B&W).

The basic goal of the LIMB Demonstration is to extend LIMB technology development to a full-scale application on a representative wall-fired utility boiler. The successful retrofit of LIMB to an existing boiler is expected to demonstrate that (a) reductions of 50% or greater in $SO_x$ and $NO_x$ emissions can be achieved at a fraction of the cost of add-on FGD systems, (b) boiler reliability, operability, and steam production can be maintained at levels existing prior to LIMB retrofit, and (c) technical difficulties attributable to LIMB operation, such as additional slagging and fouling, changes in ash disposal requirements, and an increased particulate load, can be resolved in a cost-effective manner. The primary fuel to be used will be an Ohio bituminous coal having a nominal sulfur content of 3% or greater.

The Demonstration project consists of several distinct phases - a preliminary phase to develop the LIMB process design applicable to the host boiler, a construction and start-up phase, and an operating and evaluation phase - as shown on the project schedule (Figure 1). The first major activity, the development of the Edgewater LIMB design, was completed in January 1986, and detailed engineering is now under way. Major boiler-related components will be installed during a September 1986 boiler outage. The expected start-up date is March 1987.

The preliminary design phase of the project recognized the dynamic state of LIMB technology development at the time of contract award. A 1-year study period was allocated to evaluate on-going LIMB development work to provide resolution of most of the technical issues affecting process design. During this period, the contractor worked closely with EPA researchers and contractors and conducted limited studies on his own to refine the selection of LIMB design parameters. The remainder of this paper discusses the preliminary design and the research results which support the selection of design variables.

## LIMB DESIGN ISSUES

A primary reason for the interest in sorbent injection is that the equipment requirements are simpler than those for other control technologies. However, since sorbent injection is much more closely coupled with the boiler, it must be designed for specific boiler characteristics and for compatibility with existing operating conditions. A generalized LIMB process diagram is shown in Figure 2.

A number of major issues have been identified as being critical to the design and operation of a successful LIMB system. These issues can be summarized as follows for the Edgewater design:

- Development of a fundamental understanding of reaction chemistry and kinetics to enable optimization of system conditions for maximum LIMB performance.
- Selection of a sorbent that is sufficiently reactive for the $SO_2$ removal objectives and which is or can be produced commercially at a reasonable cost.
- Characterization of the Edgewater boiler temperature and velocity profile to identify the conditions under which injection must take place.
- Design of an injection system that will disperse the sorbent into the boiler under the optimum reaction conditions.
- Selection of a burner that satisfies low-$NO_x$ goals and is compatible with the physical dimensions and requirements of the Edgewater boiler.
- Evaluation and/or modification of the particulate control system to enable collection of the increased amount of ash.
- Design of an environmentally acceptable waste handling and disposal technique.

Each of these issues is being addressed in the EPA LIMB program, with the most pertinent information being translated into recommendations for the Edgewater design.

Fundamental Considerations - From a chemical process standpoint, sorbent injection is a complex technology that requires a reasonable understanding of the interrelationships among the chemical and physical processes to enable design of a workable process. Several major reactions take place, the most important of which are calcination of the calcium sorbent to an active calcium oxide followed by sulfation with $SO_2$ in the flue gas to produce calcium sulfate. Sintering of the calcined material may also occur under certain conditions resulting in reduced reactivity. Rates and extent of reaction can be influenced by a number of factors with each favored by some conditions and not by others. Research results have shown that achieving good sorbent reactivity and a high degree of sulfation is best roughly in the temperature range of 950 to 1250°C (1600 to 2300°F). Temperatures much above 1250°C (2300°F) result in sintering and deactivation via fly ash sorbent/interaction and fusion. Calcination and sulfation reaction rates are too low below 850°C (1600°F) to be viable. The sulfation reaction is also highly sensitive to residence time so that determining optimum injection location is a critical factor in the success of LIMB.

It was originally thought that sorbent could be injected through the burners; however, pilot combustion study results showed that burner injection is not as effective as downstream injection. The poor performance of burner injection is thought to be due to sintering and fly ash/sorbent interactions in this high temperature region. Further studies using pilot plant combustion systems have shown that the optimum injection point is at a point in the furnace where the combustion gas is approximately 1200 to 1250°C (2200 to 2300°F). In the Edgewater boiler, this point is in the upper furnace just above the furnace nose. Although offering the best temperature, this region experiences a very rapid decrease in gas temperature down to 850°C (1600°F) in the convective section. It becomes a special concern to design an injection system to achieve thorough mixing of the sorbent and combustion gases to enable reaction in the short residence time available.

Sorbent Selection - Selecting an appropriate sorbent and determining the type of preparation required to produce an optimum sorbent are vital to the technical and economic viability of sorbent injection. A wide range of calcium-based materials have been evaluated, varying in calcium form and content, content of magnesium and other materials, and type and degree of preparation.

In almost all cases during pilot combustion studies, hydrated lime [$Ca(OH_2)$] sorbents performed better than lime and raw limestone sorbents. Although dolomitic hydrates generally performed better than calcitic hydrates on a calcium/sulfur basis, this higher utilization is offset by the lower calcium content of dolomites, which requires a greater mass feed rate. Although $SO_2$ removal from the gas stream is directly proportional to the molar ratio of calcium to sulfur, practical considerations, such as handling the increased particulate load, limit this operating ratio to 2-2.5.

A number of candidate calcitic hydrate sorbents produced within the general geographical area of the Edgewater plant have been evaluated under combustion conditions. The results showed that there was little difference in the reactivity of the candidate sorbents. However, these and other tests indicate that the smaller (<5 $\mu$m) particles separated from a typical size distribution range of a commercial sorbent sample tend to be more reactive than larger particles of the same sample. This has been attributed to the avoidance of pore diffusion resistance of $SO_2$ into the particle. Further work has shown that a number of sorbent production alternatives favor generation of smaller particle size sorbents - use of fresh lime in hydration, slower addition of water during hydration, and use of a separator to remove large particles from the product, to name a few. The Demonstration contractor will be working with the candidate sorbent suppliers to obtain a reasonably priced, commercially produced sorbent for the Demonstration based on current knowledge of sorbent requirements.

Boiler Characterization - Due to the critical importance of boiler temperature and velocity profile on sorbent reactivity and sorbent mixing with combustion gases, a considerable effort was undertaken to characterize the Edgewater boiler. The work included flow characterization in a 1:15 scale acrylic model of the boiler, use of a computational boiler code to estimate temperature profiles, and direct measurement of temperature and velocity at selected points in the boiler.

Compilation and evaluation of this information show important implications for sorbent injection. The temperature zone of highest reactivity is located in the upper furnace from a plane just above the nose to a plane farther back in the convective section (Figure 3). A reduction in boiler load simply moves this zone closer to the boiler nose. Bubble streak flow visualization in the scale model showed that flow velocity increases near the nose, as would

be expected, and that the flow is nearly uniform across the width of the boiler. Injection will take place at the plane of the nose in the high velocity region with sufficient injection velocity to penetrate and distribute the sorbent within the furnace. The residence time in the optimum temperature window is very short, on the order of 1 second, indicating that this boiler will be a rigorous test for sorbent injection.

Sorbent Injection - The design of an effective sorbent injection sytem will ensure rapid dispersion at approximately 1250°C (2300°F) for maximum reactivity and maximum time in the reaction zone. While considerable progress has been made in predicting penetration and distribution patterns for various injection schemes, the relationship between sorbent distribution and sulfur capture is less predictable. Based on present understanding, development of an optimum injector design is an iterative process based on use of a combination of predictive tools and experimental investigation aimed at getting an even distribution of sorbent across a plane in the boiler. Based on boiler geometry and operating characteristics, a number of practical injection designs can be considered and refined using predictive techniques. The most promising injection combinations can then be evaluated experimentally using scaled-down boiler models to select an injection scheme that will give an optimum mixing pattern in the boiler. An acrylic 1:15 scale model of the Edgewater boiler used in cold flow injection studies is shown in Figure 4.

Based on the Edgewater boiler geometry, boiler combustion air limitations, and expected injection patterns, a flexible injection scheme has been proposed consisting of two rows of eight injectors each at and just above the nose level on the boiler front wall and two and four side wall injectors at these two levels, respectively. Provision has been made for variable injection velocities and the ability to tilt the injectors ±15° from horizontal. The most likely operation of the injectors will be injection through both levels with a higher injection velocity in the lower level to enable penetration into the bulk of the flue gas stream.

Burner Selection - The $NO_x$ control component of LIMB at the Edgewater site will be implemented by replacement of the existing B&W circular burners with low-$NO_x$ burners in which peak flame temperatures are lowered to reduce $NO_x$ formation. A number of commercial low-$NO_x$ burners are available, but B&W burners were preferred because of their compatability with existing burner openings and boiler peripherals. Objectives for the burner were to reduce the $NO_x$ emissions level to approximately 129 to 172 ng $NO_x$/J (0.3 to 0.4 lb $NO_x$/$10^6$ Btu), produce a flame length of less than 6.7 m (22 ft) to avoid flame impinge-

ment on the back wall, and operate with a secondary air pressure drop of less than 15 x $10^{-3}$ kg/$m^2$ (6 in. of water) to avoid costly changes in existing fan equipment.

Although a B&W Dual Register Burner (DRB) is commercially available for low-$NO_x$ emissions, there was a question about this burner's ability to operate within the restricted front-to-back-wall distance available for flame length. A screening test program using a single burner was conducted on EPA's Large Watertube Simulator (LWS) using the DRB and two other burners - a Babcock-Hitachi burner and a new B&W burner, designated the XCL. The Babcock-Hitachi burner, a new design now in commercial operation in Japan, is reported to produce very low $NO_x$ emissions, while the XCL burner is aimed at emissions comparable to those achieved by the Japanese burner. All three burners were designed for 9 MW (79 x $10^6$ Btu/hr) to match the output of a single burner in the Edgewater boiler.

The 3-month testing program showed that none of the three burners fully met all criteria for Edgewater application. Table 1 summarizes representative data on these three burners. The low-$NO_x$ levels achieved by the DRB are achieved at the expense of long flame length and could not be reproduced within the confines of a 6.7 m (22 ft) flame length. The Hitachi burner can operate at low-$NO_x$ levels and reasonable flame length, but does so at the expense of a high pressure drop required to impart a swirl to the secondary air. The XCL burner met the flame length and pressure drop requirements, but did so with slightly higher $NO_x$ emissions than expected. A choice was made to conduct testing and optimization of the XCL burner to reduce $NO_x$ emissions and proceed with the XCL burner as the burner of choice in the design.

Table 1. Burner Test Results

| Burner | $NO_x$ ng/J (lb/$10^6$ Btu) | Flame Length m(ft) | Windbox Pressure cm. $H_2O$ (in. $H_2O$) |
|---|---|---|---|
| DRB | 107 (0.25) | >6.7 (>22) | 11.7 (4.6) |
| | 356 (0.83) | 5.5 ( 18) | 15.2 (6.0) |
| Hitachi | 145 (0.34) | 6.1 ( 20) | 19.1 (7.5) |
| | 125 (0.29) | 5.8 ( 19) | 33.5 (13.2) |
| XCL | 197 (0.46) | 6.1 ( 20) | 8.9 (3.5) |
| | 231 (0.54) | 4.9 ( 16) | 14.0 (5.5) |

Particulate Control - Although the LIMB technology is not a scheme for controlling particulate emissions, particle control is an important consideration in all LIMB applications. There are three particulate concerns with the LIMB process - the loading may increase by a factor of two to three, the particle resistivity may increase by 100-fold, and the mean particle size will be lowered - all of which make particulate control more difficult. These particulate effects are especially of concern in retrofit applications where existing electrostatic precipitators (ESPs) were designed to meet applicable mass emission rate and visibility regulations without sorbent addition.

The Edgewater ESP is somewhat unique for boilers of the Edgewater vintage in that it was retrofitted to the unit in 1982 and is substantially oversized for its present duty. Estimates indicate that existing emission standards can be met even with LIMB addition with this ESP. Other boiler LIMB retrofits may, however, have to consider construction of additional ESP surface area, prechargers, and/or gas conditioning (humidification, $SO_3$ addition) to remain within existing emission requirements.

The Test Plan for the Demonstration will include a time period in which the ESP operation will be altered to simulate a marginal ESP to enable a more general assessment of the LIMB effects on the ESP. Consideration is also being given to construction and operation of a flue gas humidification system just before the ESP to develop further information on the effects of gas conditioning.

Waste Handling and Disposal - Application of LIMB creates an additional waste load and a change in ash properties. The present Edgewater waste handling and disposal system is a dry system in which ash is pneumatically removed from the ESP bottom to an ash silo, sprayed with a small amount of water in a pug mill for dust control, and trucked to a nearby landfill. An engineering analysis has determined that the existing dry handling system is sufficiently large to handle the additional waste load.

Because of the unavailability of large quantities of LIMB-modified ash for testing, LIMB waste material was generated at Southern Research Institute using a pilot combustor with Demonstration coal and sorbent. Testing of this material under conditions specified in the Resource Conservation and Recovery Act (RCRA) showed (Table 2) that leachable toxic materials were far below levels considered to be hazardous, that rain runoff from the stored material would appear to meet required pH levels, and that ignitability and reactivity are not a problem. Current plans are for the LIMB-modified ash to be disposed of in an existing landfill but separated from conventional ash storage for observation and testing.

Table 2. Leachate Data for Simulated LIMB Demonstration Waste Products

| Metal | Allowable Limit Per RCRA[a] | Demo Coal/ Hydrate A[a] | Demo Coal/ Hydrate B[a] |
|---|---|---|---|
| Arsenic | 5 | 0.0145 | 0.0210 |
| Barium | 100 | 4.11 | 4.24 |
| Cadmium | 1 | 0.00095 | <0.0005 |
| Chromium | 5 | 0.0394 | 0.0240 |
| Lead | 5 | <0.0030 | 0.0045 |
| Mercury | 0.2 | <0.0003 | <0.0003 |
| Selenium | 1 | 0.0296 | 0.0228 |
| Silver | 5 | <0.0005 | <0.0005 |
| pH | 12.5 | (12.4/12.2)[b] | (12.4/12.2)[b] |

a. Concentration in extract in mg/l.
b. Before/after acid addition

An active effort is being made by EPA and others to produce a saleable product from the LIMB waste, including pelletizing into a useable aggregrate, use in neutralization of acidic wastes, and recycle of unreacted sorbent back to the LIMB process, all with the aim of reducing process costs. If these techniques can be scaled up and shown to be applicable to the Edgewater conditions, they will be incorporated into the Edgewater waste control scheme.

A detailed evaluation of the waste handling and disposal system will be made during the Demonstration to ensure that any potential problems are resolved.

## EPA LIMB PROGRAM STATUS AND PLANS

While support of a successful Demonstration is a short-term goal of EPA's LIMB Program, EPA is actively investigating areas which would improve the effectiveness, reduce the cost, and broaden the application of LIMB technology. There appears to be a significant potential for improving sorbent performance by altering production procedures to produce high surface area sorbents and by adding small amounts of mineral promoters and catalysts to enhance sorbent activity. Process analysis has indicated that substantial benefits may be derived from the recycle of unreacted sorbents in the flue gas. It has also been shown that addition of downsteam humidification has the effect of increasing sulfur removal from LIMB through the utilization of unreacted sorbent in the flue gas. In addition, the utilization of LIMB ash has significant potential economic benefit.

Congress has appropriated funding to demonstrate LIMB on a full-scale tangentially fired boiler. R&D emphasis in the LIMB Program will be shifted to tangentially fired boiler application in the prototype work to support this full-scale demonstration of LIMB. Additional effort will also be placed on generalization of LIMB technology for widespread application and commercialization; these efforts will include continued development of process models to provide a methodology for site-specific design and continued process analysis to evaluate applicability and costs for specific applications.

## SUMMARY

The EPA LIMB Program has developed an understanding of key processes governing the control of sulfur emissions from coal-fired utility boilers with dry sorbent injection. An engineering evaluation of this information has resulted in the development of a process design for the retrofit LIMB system to a 105 MW wall-fired utility boiler and a planned 1-year demonstration of system operation. The Demonstration process design is described with pertinent research program results which support the choices of design variables. The LIMB Program will continue to investigate areas which will improve the effectiveness, reduce the cost, and broaden the applicability of LIMB technology.

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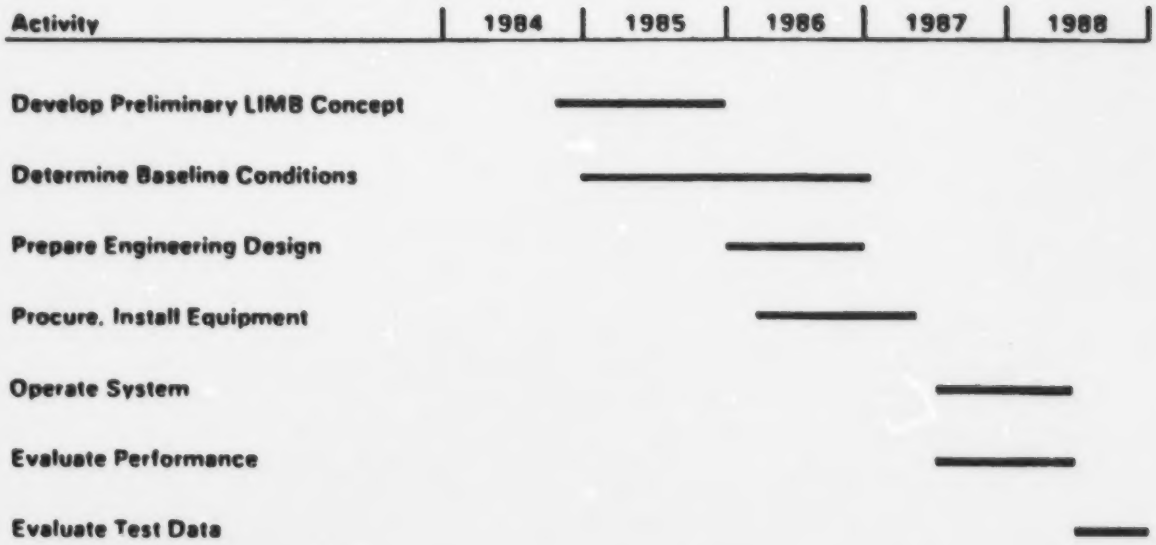


Figure 1. Project Schedule

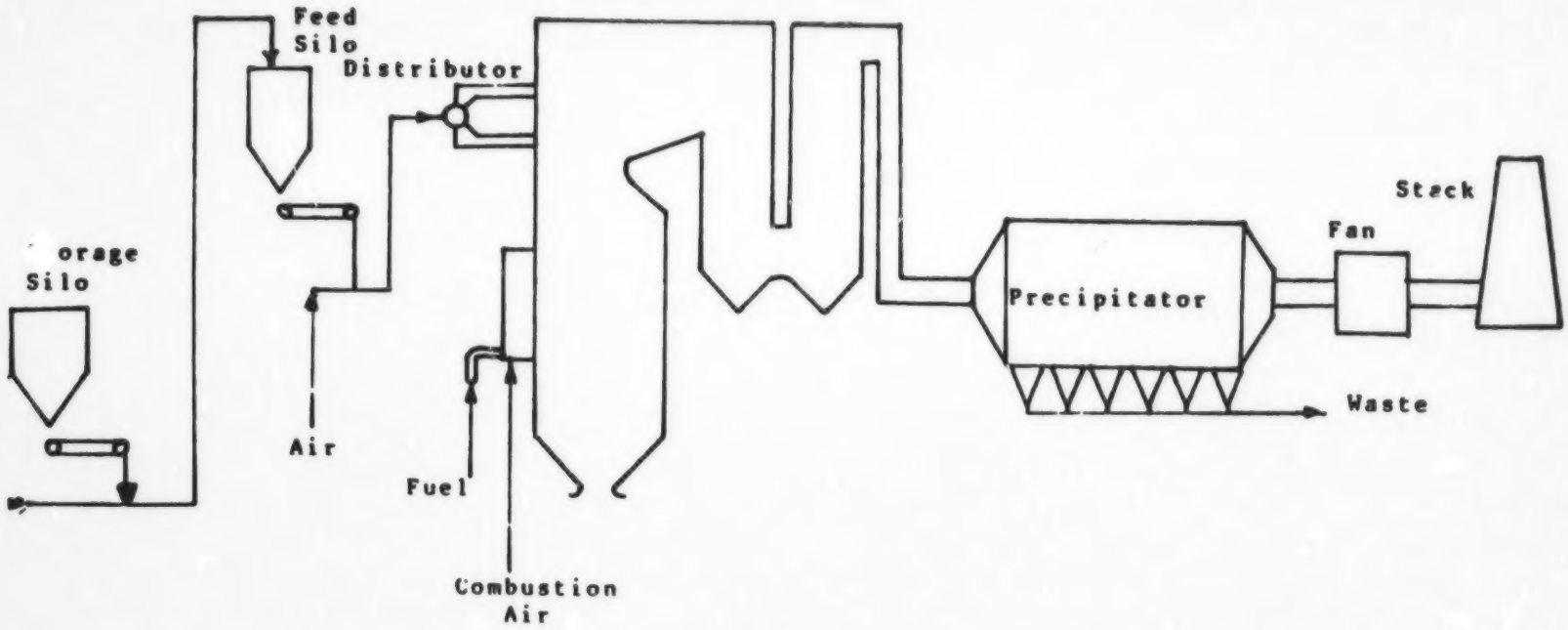


Figure 2. LIMB Process Diagram

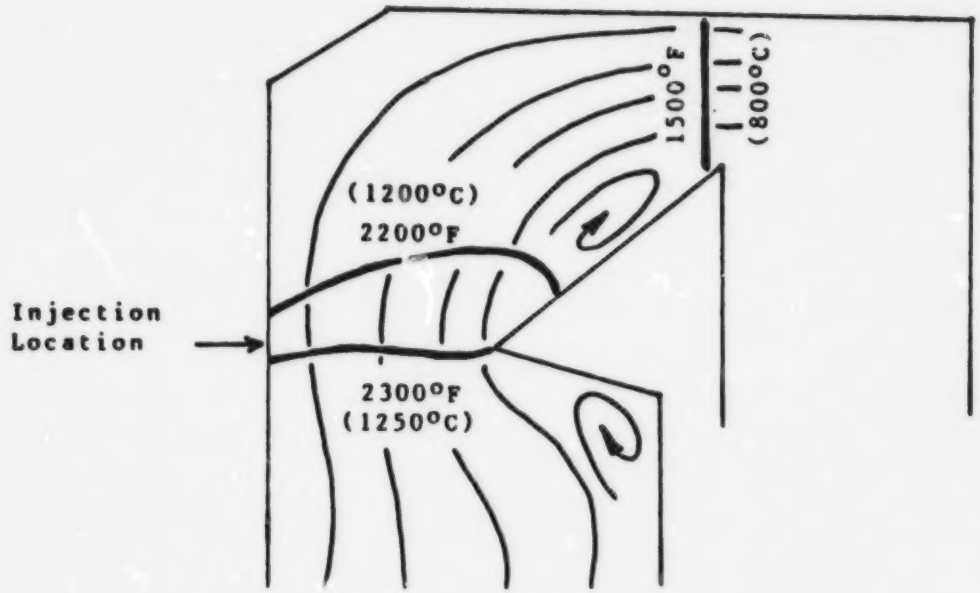


Figure 3. Location of Sulfation Temperature Window and Estimated Flow Pattern in Edgewater Boiler

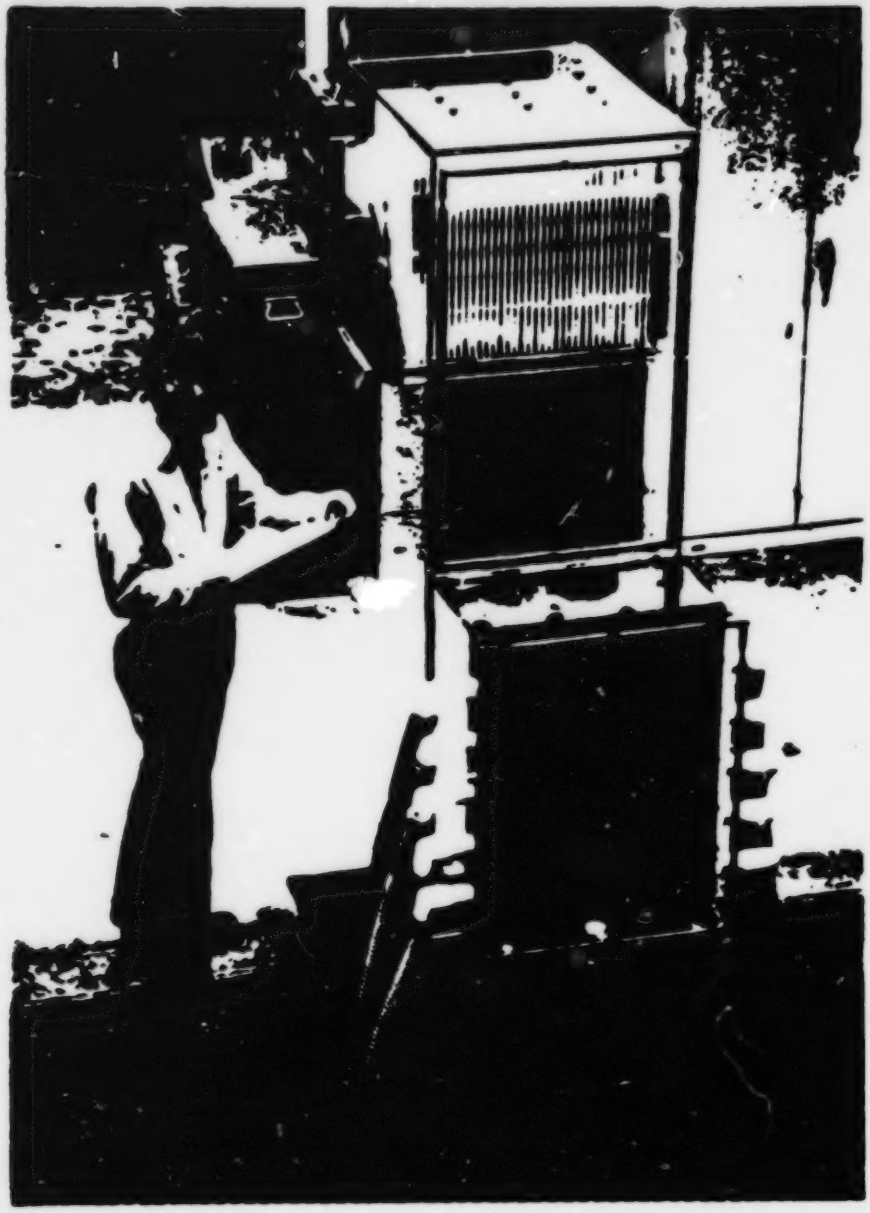

Figure 4. General View of the Edgewater Boiler Isothermal Flow Model